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ORIGINAL ARTICLE

The effect of backward walking observational training on gait parameters and balance in chronic stroke: randomized controlled study

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ABSTRACT

BACKGROUND: Backward walking (BW) and action observation training may potentially help people at risk of falls. Moreover, action observation training could be a potential intervention to improve gait after a stroke.
AIM: We aimed to identify the effects of BW action observational training (BWOT) on gait parameters and balance in chronic stroke patients.
DESIGN: Randomized, controlled study.
SETTING: Rehabilitation center.
POPULATION: Twenty-four chronic stroke patients were randomly assigned to BWOT (N.=12) and landscape observational training (LOT) (N.=12) groups.
METHODS: The BWOT group performed BW after watching a video of a BW, while the LOT group performed BW training after watching a video of a landscape. Both groups received traditional therapy for 5 days per week and BWOT for 3 days a week for 4 weeks. The primary and secondary outcomes were gait and balance, respectively. Static balance was measured using the 5 Times Sit-To-Stand Test (5TSTS), the center of pressure (COP) displacement, and weight distribution (WD) of the affected side. Dynamic balance was measured using the activity-specific balance confidence (ABC) scale.
RESULTS: The BWOT group showed significant improvements in gait velocity ($p=0.001$, $\eta^2=0.470$), step length ($P=0.007$, $\eta^2=0.313$), stride lengths ($P<0.002$, $\eta^2=0.431$), 5TSTS ($P=0.021$, $\eta^2=0.231$), COP velocity ($P=0.022$, $\eta^2=0.226$), length ($P=0.001$, $\eta^2=0.504$), WD of the affected side ($P=0.033$, $\eta^2=0.193$), and ABC score ($P=0.023$, $\eta^2=0.226$) than the LOT group.
CONCLUSIONS: The 4-week BWOT training program significantly improved the gait parameters and static and dynamic balance in stroke patients.
CLINICAL REHABILITATION IMPACT: BWOT is an accessible and effective method of rehabilitation training that can also be applied to conventional therapy as a useful method for improving the gait and balance after stroke.

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Key words: Gait; Stroke rehabilitation; Physical and rehabilitation medicine.

Recently, several therapeutic approaches have been proposed to facilitate walking function recovery in poststroke patients. Central nervous system development therapy,[1] functional electrical stimulation therapy,[2] treadmill gait training,[3, 4] robotic therapy,[5, 6] and action observation training[7] have been used as interventions to improve the gait in stroke patients. Most methods focus on the effect of cortical reconstruction through repetitive physical training. Physical training is considered an effective and viable rehabilitation strategy that improves motor function recovery by promoting neuroplasticity; for example, through increased neuronal activity.[8] Also, gait training with auditory feedback was found to improve muscle activation in stroke.[9] Particularly, action observation training involves observing and imitating other people's actions,[10] and may play a vital role in walking function recovery in chronic stroke patients.[11] The premotor and parietal regions associated with the mirror neuron system are involved in observing the motion, and the motion observation/execution matching system shows activation of similar brain regions that are activated when the motion is actually performed.[12, 13] Studies have shown that the premotor regions of the brain and those similar to the parietal lobe are also activated in cases other than when behavior is performed directly.[14] In addition, backward walking (BW) training has been reported to improve gait and balance.[15, 16] Studies have reported the presence of central pattern generator circuits during gait in human. The generators are used for walking in various directions, such as forward and backward walking.[17] BW is the reverse movement of forward walking, and the muscle function in the joint is also changed in the opposite direction.[18] From a neural control perspective, forward walking and BW are different movements. However, the advantage of BW is that it can use the same muscles as forward walking and can be controlled by the same single spine mechanism.[19] Therefore, several studies have investigated the use of BW to improve the gait in stroke patients.[16, 20, 21] Previous studies have demonstrated that action observation and BW training can positively affect gait in stroke patients. Recently, Moon and Bae[22] reported that BW observation training (BWOT), which combines action observation and BW, improved the 10-Meter Walk, Timed Up and Go, and Dynamic Gait Index results in chronic stroke patients compared to those in the group who did not action observation training. As such, observation of physical behavior was more effective in mirror nervous system analysis than repetitive training without these observations.[23] The application of BWOT has been demonstrated as an effective intervention for gait improvement in stroke patients. However, studies investigating the mechanism by which BWOT improves stroke patient functioning are sporadic. In addition, the effect of BWOT on the gait parameters and balance in stroke patients is unclear. In this study, we aimed to confirm the effect of 4 weeks of BWOT on the gait parameters and static as well as dynamic balance in stroke patients. We hypothesized that BWOT would greatly improve these outcomes in this patient population when compared to LOT.

Materials and methods

Ethical considerations and study design

This study was conducted in accordance with the tenets of the Declaration of Helsinki. All participants were given detailed information on the study procedure and safety and provided written informed consent. All study procedures were approved by the Gachon University Ethics Committee and the Institutional Review Committee (clinical trial registration number: KCT0004963). This was a randomized controlled trial. Blocking was used to ensure equal numbers of participants in the BWOT and LOT groups. Participants were randomly assigned to either group depending on a code that was within a sealed, opaque envelope. Randomization was performed by an investigator who had no relation to the recruited participants. Simple randomization was performed using Microsoft Excel (Microsoft Corporation, Redmond, WA, USA). Data were collected from March 2020 to May 2020.

Participants and procedure

Twenty-four stroke patients who were hospitalized at a rehabilitation center participated in this study. All participants met the following criteria: 1) a diagnosis of stroke was made between 6 and 12 months prior; 2) independent gait over 10 m was possible with or without a walking aid; 3) no visual and auditory deficits; and 4) no other medical complications. Patients who had difficulty in BW, and those with preexisting neurological disorders, left sided neglect, progressive disease, and a mini-mental state examination score below 24 were excluded. The sample size was calculated using G-Power 3.1.9 software (Heinrich Heine University Dusseldorf, Dusseldorf, Germany). To calculate the sample size, we used a repeated measure analysis of the variance within and between the interactions. The alpha error probability and power were set to 0.05 and 0.8, respectively. Additionally, the effect size was set at 0.30. The number of groups and measurements were set to 2 and 2, respectively.[24] When clinically significant interactions were observed between time points and groups, a sample size of 24 was required to demonstrate statistical significance. This study initially recruited 34 stroke patients. After applying the inclusion and exclusion criteria, 29 participants were selected and randomly assigned to the BWOT and LOT groups. However, 5 participants dropped out during the study, 2 did not complete the study for personal reasons, and 3 were discharged from the center. Thus, the final study population consisted of 24 participants, 12 in each group. The participants' general characteristics, gait parameters, and balance were measured before and after the intervention. All data were measured by the same blinded physical therapist before and after the 4-week intervention. Although researchers were aware of the allocated groups, outcome assessors and data analysts were blinded to the allocation. All par-

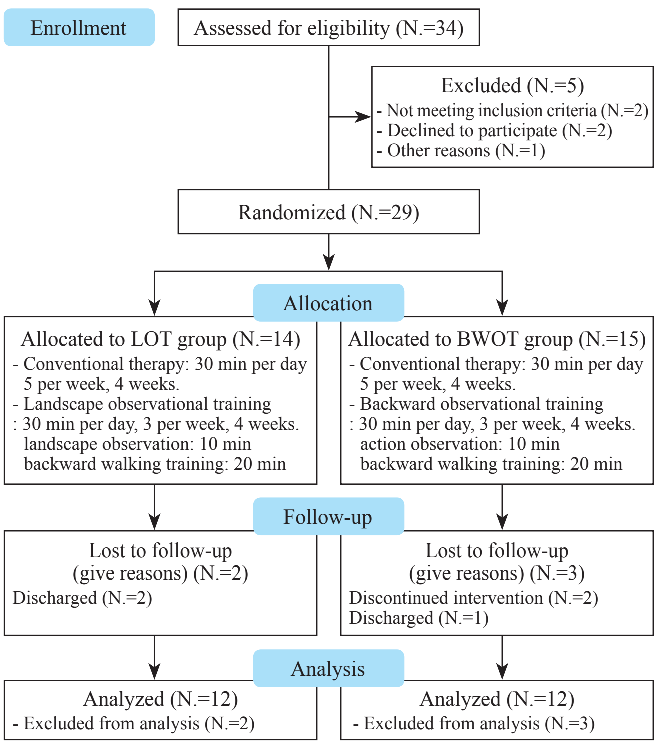

Figure 1.—Study flow chart.
BWOT: backward walking observation training; LOT: landscape observation training.

ticipants received conventional therapy (CT) for 30 minutes. The BWOT group watched a 10-minute BW video and performed 20 minutes of BW training thereafter. The LOT group watched a 10-minute landscape video and performed 20 minutes of BW training thereafter. The interventions for both groups were 30 minutes in duration each time. These interventions were repeated 5 times a week for 4 weeks; a total of 20 sessions per participant (Figure 1).

Outcome measurements

The primary outcome measure was the spatiotemporal gait parameter. To determine the balance, both the static and dynamic balance were measured as a secondary outcome. Static balance was measured using the 5 Times Sit-To-Stand Test (5TSTS) and center of pressure (COP) displacement. Dynamic balance was measured using the activity-specific balance confidence (ABC) scale. The spatiotemporal gait parameters were calculated using the Zebris platform (FDM 1.5, Zebris Medical GmbH; Isny im Allgäu, Germany). The platform size was 1580 mm × 605 mm × 21 mm (length × width × height). A pressure distribution measurement system, with a resolution of approximately 4 sensors per cm^2 and a sampling rate of 100 Hz, was used to measure the gait parameters and static balance. The following gait parameters were measured: step and stride lengths, cadence, and gait speed. Since the most effective single indicator of the health status in the clinical evaluation was the 10-Meter Walk Test,[25] we set the gait speed at a 10 m walking speed. The 5TSTS was performed according to the protocol described by Franco *et al.*[26] Participants sat upright on a height-adjustable table with no backrest or armrest. They placed the arms on the chest, and both feet were a shoulder-width apart and placed on the Zebris platform (FDM 1.5, Zebris Medical GmbH; Isny im Allgäu, Germany). To allow the participants to accustomize to the movements, they were asked to perform 3 exercises. The time taken to fully stand up and sit on the command of "Start" for 5 repetitions was recorded. After the 5TSTS, the patient was allowed to stand for approximately 30 seconds. The COP displacement was measured while standing after the 5TSTS. COP measurements were reliable for 30 seconds while standing upright.[27] The raw COP data were measured using the platform. We also measured the path length (cm) and speed (cm/s) of COP displacement and weight load distribution on the affected and unaffected sides. The ABC scale has been used in a variety of groups, including older adults and stroke patients.[28] It helps measure the patient's confidence in their dynamic walking balance without falling, both at home and outside. Participants were instructed to walk for at least 30 minutes on the rehabilitation center premises, and they were given a 16-item questionnaire that rated their confidence from 0% (no confidence) to 100% (very confident). The average score was considered the total balance confidence score per activity, with higher scores indicating a higher confidence level. The Korean version of the ABC scale was used in this study.[29] The internal consistency reliability of the ABC scale was 0.94, and the test-retest reliability was good with an intra-class correlation coefficient of 0.85 (95% confidence interval, 0.68–0.93).[30] All variables, except the ABC scale score, were measured thrice, and the average score was used. All data were collected at the rehabilitation center where the participants were hospitalized, and all assessments were performed by the same therapist who worked at the center.

Interventions

All patients received CT, which consisted of trunk exercises, lower extremity strengthening exercises, posture control, as well as weight-bearing and weight-shifting exercises that were indicative of more advanced movement patterns. The patients received CT for 30 minutes per ses-

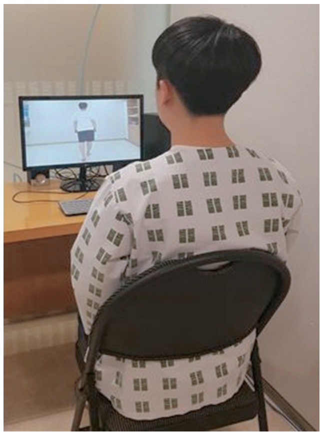

Figure 2.—Action observation training for participants of the backward walking observation training group.

sion, 5 times a week, for a total of 20 sessions per patient, over 4 weeks. After CT, the BWOT group watched a video that consisted of 10 minutes of walking backwards in a straight line, in a curve, on unstable ground, and in a zigzag in a noisy room (Figure 2). For 10 minutes, the LOT group watched a landscape photography video that only consisted of landscape paintings with no human or animal movement. All participants watched the video while sitting on a chair placed 1 m away from a 24-inch monitor. To help the participant focus on the task, the video was played in a noise-free environment. All participants were given a 2 minutes break after they watched their respective videos. Thereafter, the subject performed BW for 20 minutes. Each participant controlled their own BW motion and speed without using walking aids. The therapist instructed the participants on how to complete the task safely without falling. The BWOT (BW observation + BW training) and control (landscape observation + BW training) groups performed the actions for 30 minutes per session, 3 times per week, for 4 weeks, for a total of 12 sessions per participant. Every participant received a one-to-one guided session for CT and BW training by the same physical therapist during the study period. All participating physical therapists were qualified and had varying levels of experience in the Department of Rehabilitation Medicine at participating rehabilitation centers.

Statistical analysis

All statistical analyses were performed using IBM SPSS Statistics for Windows, version 24 (IBM Corp., Armonk, NY, USA). Mann-Whitney U test and χ^2 test were conducted to analyze the general characteristics of the 2 groups. The general characteristics of the subject were analyzed using descriptive statistics. Wilcoxon signed-rank test, a nonparametric test, was used for intra-group comparison, and the Mann-Whitney U test was used to compare the differences between groups. The difference between groups was calculated as ([4 weeks - baseline] / 4 weeks) * 100 (%). The effect size was calculated as $\eta^2=(Z^2 / [N-1])$ to determine the significant intergroup changes.[31] An effect size of up to 0.02, 0.13, and 0.26 indicated small, moderate, and large changes, respectively.[32] All values are expressed as mean±standard deviation (SD). A P value <0.05 was considered statistically significant.

Data availability

The data associated with the paper are not publicly available but are available from the corresponding author on reasonable request.

Results

Table I summarizes the general characteristics of the 24 stroke patients included in this study. We observed a significant difference between the BWOT and LOT groups in the following gait parameters: velocity, step length, and stride length (P=0.001, P=0.007, and P=0.002; η^2=0.470, η^2=0.313, and η^2=0.431, respectively). In addition, a significant difference between the 2 groups was noted in the fol-

Table I.—*Baseline characteristics of the participants.*

	Experimental group (N.=12)	Control group (N.=12)	P value
Sex (male/female)	4/8	7/5	0.219*
Diagnosis (infarction/hemorrhage)	9/3	10/2	0.615*
Age (years)	57.75±10.95	52.83±8.86	0.174†
Height (cm)	162.60±7.15	166.17±6.03	0.056†
Weight (kg)	58.53±8.37	63.88±7.80	0.024†
MMSE (score)	26.25±2.46	26.58±2.46	0.726†
Onset time (months)	8.67±2.46	9.50±2.27	0.446†

Values are expressed as mean±standard deviation.
MMSE: mini-mental state examination.
*Statistical analysis was performed using the Chi-square test; †statistical analysis was performed using the Mann-Whitney U test.

TABLE II.—*Comparisons of gait parameters and balance between before and after intervention.*

Variables	Backward walking observational training group				Landscape observational training group				Between group	
	Baseline	4 weeks	P	Difference (%)	Baseline	4 weeks	P	Difference (%)	Z (P)	η^2
Gait parameter										
Velocity (cm/sec)	3.99±1.50	5.15 ±1.83	0.002	22.96±8.31	4.04±1.90	4.47±1.96	0.002	10.45±5.28	-3.291 (0.001)	0.470
Step length (cm)	29.00±14.69	32.58±14.31	0.002	14.15±9.47	32.33±17.46	33.38±17.70	0.024	5.10±4.03	-2.686 (0.007)	0.313
Stride length (cm)	64.17±25.10	71.17±23.62	0.002	11.60±7.16	73.58±35.71	75.08±36.50	0.090	-2.20±3.71	-3.149 (0.002)	0.431
5TSTS (sec)	24.41±7.30	22.65±6.71	0.002	-7.75±4.07	26.74±11.11	25.87±10.88	0.006	-3.71 ±3.31	-2.309 (0.021)	0.231
COP velocity (mm/sec)	18.50±8.29	13.83±5.75	0.003	-31.07±24.53	16.83±8.11	15.33±7.63	0.007	-10.99±8.07	-2.283 (0.022)	0.226
COP length (mm)	185.75±83.08	157.00±68.38	0.002	-17.83±6.99	136.58±74.19	127.92±71.27	0.003	-7.25±5.12	-3.407 (0.001)	0.504
Affected side WD (%)	37.25±6.77	42.50±2.93	0.003	12.62±12.56	39.67±3.16	41.42±2.20	0.006	4.35±3.84	-2.110 (0.033)	0.193
ABC (score)	651.67±239.61	818.33±252.36	0.002	21.86±10.17	637.50±337.56	714.17±333.80	0.002	12.48±6.63	-2.281 (0.023)	0.226

5TSTS: 5 timed sit-to stand test; COP: center of gravity; WD: weight distribution; ABC: Activities-specific balance confidence scale.

lowing balance variables: 5TSTS, COP velocity and length, weight distribution (WD) of the affected side, and ABC scale score (P=0.021, P=0.022, P=0.001, P=0.033, and P=0.023; η^2=0.231, η^2=0.226, η^2=0.504, η^2=0.193, and η^2 =0.226, respectively). In the BWOT group, the velocity, step and stride length from the gait parameters (P=0.002, P=0.002, and P=0.002), and the 5TSTS, COP velocity and length, WD of the affected side, and ABC scale score showed significant improvement after intervention compared to the values before intervention (P=0.002, P=0.003, P=0.002, P=0.003, and P=0.002, respectively). In the LOT group, the velocity, step and stride lengths, 5TSTS, COP velocity and length, WD of the affected side, and ABC scale score improved significantly after the intervention than before intervention (P=0.002, P=0.024, P=0.090, P=0.006, P=0.007, P=0.003, P=0.006, and P=0.002, respectively) (Table II).

Discussion

This study aimed to determine whether BWOT could significantly improve the gait parameters, static balance, and dynamic balance compared to LOT in stroke patients. Both BWOT and LOT improved these outcomes after the intervention when compared to before the intervention. Moreover, the changes in the gait parameters and static and dynamic balance with BWOT were more significant than those with LOT. Therefore, the results of this study supported our research hypothesis that BWOT would be more effective in improving the gait parameters as well as static and dynamic balance in stroke patients compared to LOT. To the best of our knowledge, this is the first study to demonstrate the effectiveness of BWOT in improving gait parameters and balance in stroke patients. Gait is the most pertinent problem for stroke patients, and repetitive gait training is used to assist in re-learning the actions that the patient performed before the injury. Of the gait training methods, BW training is an important, feasible, additional method that is used in stroke rehabilitation to improve gait and balance.[16, 20, 21] Chen *et al*.[33] systematically reviewed the effect of BW on stroke patients and reported that BW had a positive effect on gait velocity and paralytic step length. Our findings suggest that the gait parameters as well as static and dynamic balance improved in both the BWOT and LOT groups. These results were similar to those of previous studies, thus establishing the reliability of this study method and confirming that BW as a training method can improve the gait and balance in stroke patients. Action observation training was developed based on the idea of mirror neurons that fire when one person performs a movement or observes another person's movement.[34] It increases motor cortical excitability and is associated with cognitive processes such as the ability to understand other people's actions and intentions, motor learning, and motor memory formation.[20, 35] Consequently, action observation has been proposed as an alternative approach to rehabilitation.[36] Zhu *et al*.[37] reported that upper extremity movement improved greatly when the same movement was performed after it was observed. In addition, stroke patients who trained using the same movement after observing the BW movement demonstrated a significant improvement in their 10-Meter Walk Test, Timed Up and Go, and Dynamic Gait Index.[22] In the present study, the BWOT group, who underwent BW training after BW observation, showed a significant improvement in their velocity, cadence, step, and stride length during walking when compared to the LOT group, who only performed BW training. In particular, the η^2 (effect size) of the velocity, step and stride length were 0.470, 0.313, and 0.431, respectively. When $\eta^2>0.25$, the intervention effect is considered large.[32] The gait velocity is used as the main form of evaluation of stroke disability and walking function recovery,[38] and interventions that improve the step and stride lengths can help increase the walking speed of stroke patients.[39] Therefore, we propose that BWOT as an intervention can improve the gait more efficiently than LOT. Only performing BW mildly impacted the walking speed and the walk test.[33] However our findings show that the effect size of BW after BW observation was very large. Therefore, we believe that BWOT is a more efficient method of improving gait parameters than LOT. An asymmetric WD after a stroke is associated with postural instability,[40] and is particularly closely related to the dynamic balance.[41] Therefore, an increase in WD on the affected side could reflect the improvements in the postural stability and dynamic balance. In this study, the WD of the affected side was significantly improved by 12% compared to preintervention, from 37% to 42% in BWOT group. An increase of WD of the affected side above 40% increases postural stability and improves independent walking.[42, 43] An asymmetric WD is associated with postural sway and balance-correcting leg actions that worsen with increased leg loading.[44] Our study found that the velocity, step and stride length, and COP length improved significantly in the BWOT group compared to the LOT group. In particular, the η^2 of the COP length was 0.504, suggesting a significant effect. We propose that BWOT positively affects static and dynamic balance as it leads to a reduction in asymmetric WD in stroke patients. The results suggest that adding BWOT to CT may help improve gait and balance ability in stroke patients and may be clinically feasible as a practical aid to routine rehabilitation interventions.

Limitations of the study

Our study has some limitations. First, although the participants were randomly assigned to the BWOT and LOT groups, there was a difference in the baseline balancing ability between the groups. In addition, our findings suggest that the difference in WD may not be the same in patients with large differences. Second, we were unable to provide information on the change in the range of motion related to the walking ability because motion analysis was not performed. Third, our study duration was relatively short. We propose that a follow-up study of at least 2 months duration is required to confirm the long-term effects of BWOT. Despite these limitations, to the best of our knowledge, this is the first study to investigate the effects of BWOT on the gait parameters and balance ability in stroke patients. Therefore, it provides the foundation for further research on BWOT that will allow for improvements in the lower extremity function of stroke patients. In addition, this is clinically significant because it confirmed the effect of BWOT on walking ability as well as static and dynamic balance.

Conclusions

In conclusion, our study demonstrated that BWOT resulted in a greater improvement in the gait parameters and static and dynamic balance of stroke patients compared to LOT. Therefore, clinical rehabilitation programs that include BWOT along with conventional treatments may prove useful when aiming to improve the gait and balance in stroke patients.

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